

INTEGRATING RPAS – PUBLISHED APPROACH PROCEDURES VS. LOCAL ARRANGEMENTS

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Abstract

This paper presents the setup, the assessment methods, and the results of a flight trial that was conducted in June 2016 in order to demonstrate integration of remotely piloted aircraft systems (RPAS) into the current airspace, while also acknowledging that there are challenges to overcome. An RPAS demonstrator received a flight plan from the ground control station (GCS) using a ground-based data link, departing from Braunschweig-Wolfsburg airport and flying towards Leipzig/Halle airport on published routing. When approaching Leipzig/Halle airport, the data link was lost as predicted, and the arrival procedure was altered by air traffic control (ATC), which showed that an additional and dedicated RPAS controller at arrival airports might be valuable and advantageous.

Focus of this paper is the description of the components that were used during the trial and their interconnectivity, the evaluation of quantitative recorded data and the qualitative experienced difficulties and challenges. Assessment of the recorded data is divided into data link quality, data link latency, and flight following performance (vertical and lateral following accuracy), with the latter being linked to existing performance based navigation (PBN) parameters by ICAO and height-keeping performance values by EASA. The paper concludes with a discussion on the investigated integration concept.

Introduction

With the increasing importance of unmanned aerial systems (UAS) for various purposes and stakeholders, both military and civilian, the issue to integrate unmanned vehicles into the current airspace becomes imminent. Platforms range from small, user-friendly off-the-shelf drones (“micro UAS”) to large transportation aircraft. One possible scenario for civil UAS or RPAS operation is freight transport, ranging from small and urgent deliveries (e.g. organs or spare parts) and crisis relief (e.g. humanitarian logistics or optimal coverage of a crisis area) to scheduled large

freight transport, replacing or extending current conventional manned freight transportation. However, the airspace integration of such novel systems is still a major challenge. Within this work, a flight trial was performed to investigate several issues of the integration of large RPAS into the existing air traffic management (ATM) architecture.

A major concern is the maintenance of safety for all airspace users; manned and unmanned, commercial and private. An intuitive way of integration that is realizable within near future and without adaptations of current ATM is the usage of support systems that make the RPAS appear just like a conventional manned aircraft for ATC and other airspace users.

To realize and demonstrate this approach of RPAS integration, different systems are required. Most importantly, a stable data link is necessary to exchange information between the aircraft and the GCS. A flight management system (FMS) on board the aircraft calculates a 4D trajectory based on the requested flight plan, which can then be followed automatically by a digital autopilot, or manually by steering commands for the experimental pilot (e.g. by using a flight director). Voice communication has to be implemented via the aircraft in such a way that the air traffic controller can use the regular frequency and reach the remote pilot on the ground.

In June 2016, a flight trial with an Airbus A320, which was used as an RPAS demonstrator, was conducted. The purpose of this flight trial was to show the overall functionality of the involved systems and to prove the concept of RPAS integration into the existing airspace. The RPAS demonstrator was used to simulate an RPAS flying into a cargo hub airport (Leipzig/Halle, EDDP). The trial was analyzed afterwards to assess the overall functionality, the flight path following accuracy of the RPAS demonstrator under those conditions, and the behavior of the experimental FMS in case of a data link loss. The RPAS demonstrator received trajectory instructions from a GCS via an

experimental FMS. A ground based S band data link was used to exchange information with the RPAS demonstrator, which is based at the Institute of Flight Guidance at the German Aerospace Center (DLR) in Braunschweig. As the used data link requires a direct line of sight, it was obvious that the link would be lost at a certain time of the approach into Leipzig/Halle, which is approx. 90 NM away.

In preparation of this flight, the routing was negotiated with the responsible ATC supervisor. Standard instrumental flight rules (IFR) routing was explicitly and deliberately used to ensure predictable flight behavior. A standard instrument departure, a published en-route segment and a standard arrival route were chosen. Several different routings were prepared, all based on standard routings, to be prepared for different weather and traffic situations. For the actual flight, the published required navigation performance (RNP) procedure for runway 26R was used. This approach has a lateral routing that leads towards the parallel runway (26L) first and then leads to runway 26R for landing. In practice, this approach is not used by approaching aircraft, as they usually get radar vectors and follow a trombone procedure for the approach. This was not apparent to the people involved in the planning of the trials and led to confusion on ATC side during the trials.

In this paper, the flight test infrastructure and the results of the flight trial will be presented. It will show the behavior of the RPAS demonstrator during a data link loss and the flight path following performance during flight. Additionally, it will show that the use of an on-site RPAS controller who is aware of local procedure and capable of speaking the local language could facilitate the integration. This RPAS controller would be located at the landing airport next to the controller to assure direct communication.

Methods

DLR's Advanced Technologies Testing Aircraft (ATRA) was used as an RPAS demonstrator to demonstrate the concept and the functionality of the systems. ATRA is an Airbus A320 which was modified for scientific purposes. Flight test instrumentation was integrated to display, store and distribute the current flight data. In addition,

experimental equipment required for the given experiment is installed on board.

Setup of Flight Trial

An experimental cockpit display is installed on the right hand side of the cockpit. On this display, information which is generated by the installed equipment can be shown to the experimental pilot.

During the flight trials, the following setup was used, which is also depicted in Figure 1. A remote pilot on the ground monitors the state of the aircraft using the GCS *U-Fly*. New flight paths and direct control commands can be uplinked to the aircraft using a data link for command, control, and communication (C³). The data received by the aircraft is converted into steering commands and displayed by the on-board experimental equipment.

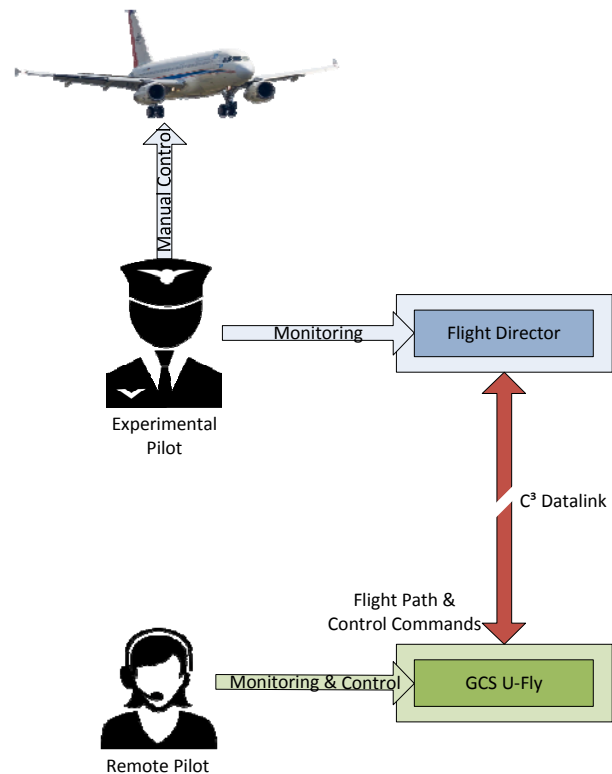


Figure 1. Setup of Flight Trial

The data presented to the experimental pilot consists primarily of a map display and a primary flight display (PFD). On the PFD, a flight director (crossbars) is displayed based on the steering commands from the ground station. The experimental

pilot on-board the aircraft follows the flight director commands manually and monitors the state of the aircraft. The state is also downlinked to the ground, using the same C³ data link, and displayed in the GCS. The safety pilot on the left side of the cockpit monitors the basic aircraft, ensures a safe flight and is responsible for the communication with the air traffic controller.

The experimental equipment was installed in two 19'' racks in the cabin of the ATRA. The equipment includes the data link units and PCs that receive the control commands and translate it into flight director commands. They also generate the display data shown to the experimental pilot. In addition, two global navigation satellite system (GNSS) receivers augmented by European geostationary navigation overlay service (EGNOS) [1] are installed for precise position information and analysis.

Flight Trial Conducted

The aim of the flight trial was the testing of the experimental systems and the usability of the data link. Especially the reconnection after the expected link loss was in focus of this trial. Therefore, a test flight from Braunschweig-Wolfsburg airport (ICAO: EDVE) to Leipzig/Halle airport (ICAO: EDDP) was conducted. First, a data link test was performed to the north and then a routing to EDDP was planned. The recorded flown track is visualized in Figure 2. In order to behave like a normal flight, a standard routing was used for the flight. In addition, a standard RNP approach was prepared. The lateral approach path can be found in Figure 4. The approach is published and free for operational use by Deutsche Flugsicherung (DFS) [2].

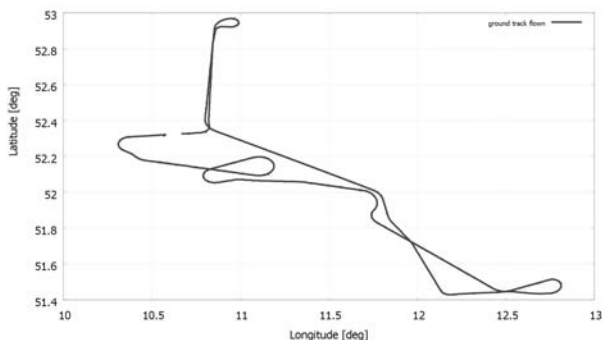


Figure 2. Ground Track Flown

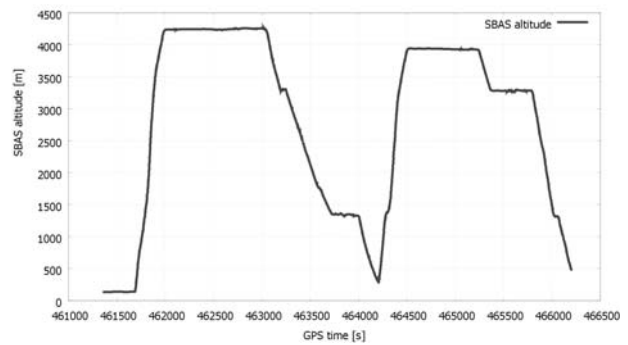


Figure 3. SBAS Altitude

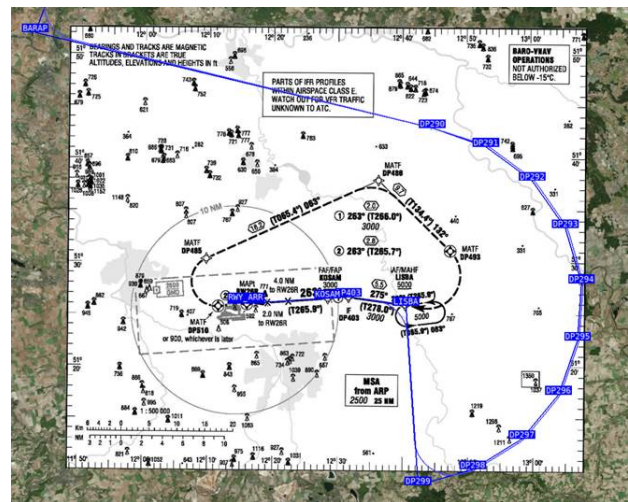


Figure 4. Approach Chart for EDDP RWY26R

Expectation was that the routing and the approach would not induce abnormal behavior, especially at the busy cargo hub EDDP. As it turned out, this type of approach was not commonly used by regular approaching traffic and led to some issues which will be described in a later section. As the airports are approx. 90 NM away from each other and the data link requires a radio line of sight (RLOS) connection, it was expected that a data links loss would occur at a certain descent altitude. Especially the reconnection after a go-around procedure at Leipzig/Halle airport was of interest here.

To ensure voice communication between the RPAS demonstrator and the GCS, a voice over internet protocol (VoIP) software was used. As long as a data link connection was established, the crew on board was able to communicate with the ground crew.

Assessment

Different measures can be applied for the validation of safety aspects. In this experiment, four different measures were chosen to show the robustness and reliability of the underlying concept considerations. One of these aspects is the maintenance of a robust and reliable C³ data link. Therefore, the data link quality and latency is examined and analyzed with regard to possible impacts to the control of the RPAS demonstrator and the communication between remote pilot and ATC.

Another important parameter when validating the safety of the flight path is the flight path following accuracy of the RPAS demonstrator during the experiment. The accuracy can be examined in vertical and horizontal dimension. Both require an analysis of the total system error (TSE) that occurred during the flight test. The TSE has two main contributors: the flight technical error (FTE) and the navigation system error (NSE). Obviously, the NSE is dependent on the used navigation system and can therefore be considered as a fixed external parameter. In addition, the NSE is usually magnitudes smaller compared to the FTE and, due to these considerations, not subject of investigations here. A third, usually small, component of the TSE is the path definition error (PDE), which describes the difference between desired and defined path of the aircraft. A visualization of the TSE and its components can be found in Figure 5.

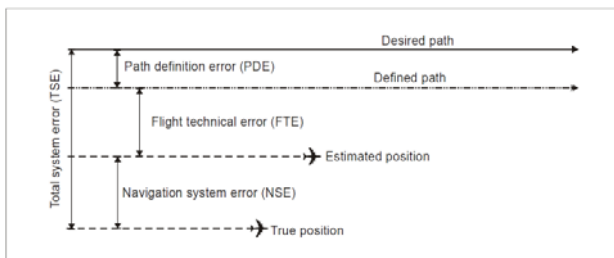


Figure 5. Flight Technical Error according to ICAO Doc 9613 [3]

The FTE value represents the ability of the aircraft guidance system to follow the computed flight path. The lateral navigation was based on a standard GNSS augmented by EGNOS and an inertial reference system. According to ICAO Annex 10 Volume I (Aeronautical Communication) [4] the horizontal accuracy during approach should

be 16 m in 95% of the time, but the typical lateral accuracy is expected to be well within 3 m. The concept of PBN can be applied to define requirements for the aircraft's lateral navigation accuracy. PBN defines navigation requirements applicable to aircraft conducting operations on specific routes, on an instrument approach procedure, or in a designated airspace. It also refers to the level of performance required for a specific procedure or a specific block of airspace. Therefore, it can be applied to determine the lateral FTE. When operating with an autopilot system, the following lateral deviations are defined by ICAO Doc 8168 (Procedures for Air Navigation Services – Aircraft Operations) [5] ensuring that the required level of performance is provided:

- a) ± 3.7 km (2.0 NM) in en-route mode;
- b) ± 1.9 km (1.0 NM) in terminal mode; and
- c) ± 0.6 km (0.3 NM) in approach mode.

In the context of this paper, these limiting values for operations can be taken as a measure of safety for the RPAS flight experiment. In detail, the cross track errors are measured in meters and compared to the performance levels required for the respective flight phases.

Another important factor when evaluating the flight following performance is the vertical performance of the aircraft. In order to ensure safe transition between regions, a global height-keeping performance specification was developed and defined for aircraft in EASA AMC 20-27A [6]. According to EASA, the aircraft's performance should demonstrate on a 99.7 percent probability that vertical errors at altitudes above mean sea level (MSL) should be less than:

- At or below 5000 ft (MSL): < 100 ft
- 5000 ft to 10000 ft (MSL): < 150 ft
- 10000 ft to 15000 ft (MSL): < 220 ft.

In this paper, the vertical height-keeping performance is determined by comparing the computed and commanded altitude to the actual uncorrected pressure altitude over the time. Both measures (altitude error [ft], cross track error [NM]) are used in this work to validate the performance level of the aircraft demonstrating an RPAS flight in non-segregated airspace.

Results

As described, the focus of this trial was on the usability of the data link and the flight path following accuracy. Therefore, these two parameters are examined here. In addition, the issues encountered are described as lessons learnt to support an integration concept that is found in a later section.

Data Link Quality and Latency

The data link quality is measured in packages per second and provides an overview of the data volume that was transmittable between ground station and aircraft during the flight experiment. Under perfect conditions, the maximum quality is 5 packages per second, while a connection is perceived as poor with a value lower than 1 package/sec. The progress of the data link quality along the flight path is displayed in Figure 6. Obviously, when having applied a terrestrial data link, the robustness of the data link is constrained by a direct line-of-sight connection. Thus, in this flight experiment the data link was foreseen to be disrupted when reaching the border of the data link coverage region (ca. 138 km distance from ground station). Within this range the data link quality remained at medium levels, showing a mean of $\mu = 1.9$ packages per second with a variance of $\sigma = 1.2$ packages per second. With this quality level provided during the experiment, all flight path and steering commands as well as voice communication could be transmitted between the aircraft and the GCS without any disruptions. The only segments significantly showing a quality decrease are the flight segment at the beginning of the flight to test the data link range (segment in north direction with procedure turn) and the approach segment to Leipzig/Halle airport (south-east part of the flight path displayed in Figure 6).

The data link latency in the experiment showed very low values. The latency was recorded with mean values of $\mu = 0.49$ seconds with a variance of $\sigma = 0.6$ seconds. Even in flight phases that required frequent updates of the flight path and strong coordination with the on-board crew (e.g. before entering the approach to EDDP), the latency remained at low levels and all data could be transmitted without any significant delay. The recorded values along the flight path (longitude/latitude) are displayed in Figure 7.

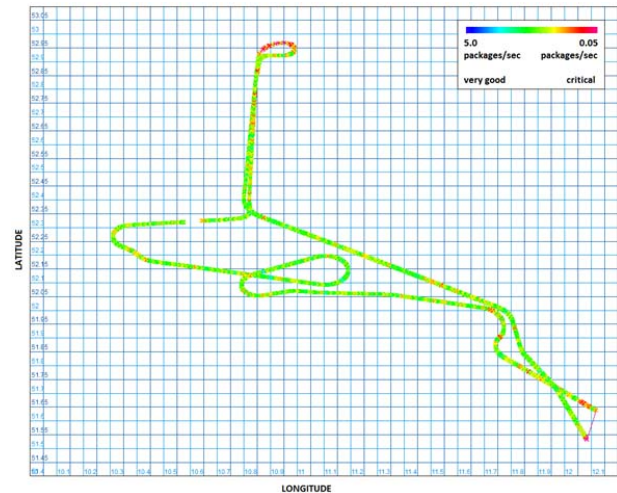


Figure 6. C³ Data Link Quality [packages/sec]

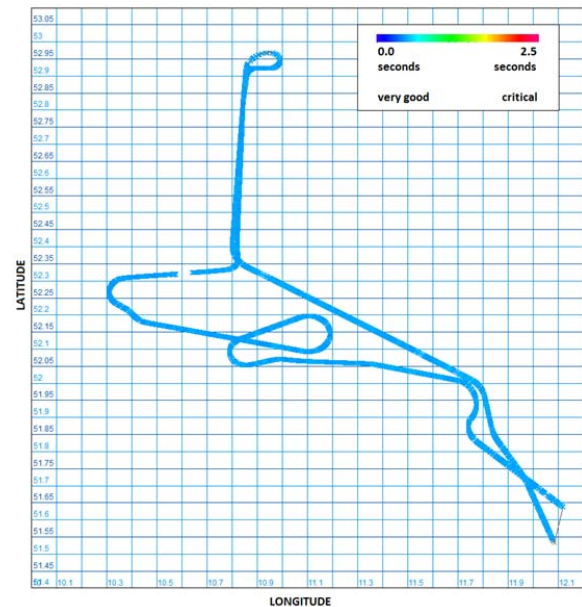


Figure 7. C³ Data Link Latency [sec]

Both data link quality and latency show a high robustness in all flight phases and during all flight maneuvers (e.g. procedure turns) within the data link's range of operation.

Flight Following Performance

The flight following performance can be examined with regard to the aircraft's lateral and vertical accuracy when following the 4D trajectory. Firstly, the lateral accuracy provided by the cross track error is discussed. The allowed deviations are strongly dependent on the flight phase of the aircraft. Therefore, the data analysis reflects mean deviations

(μ) and standard variances (σ) according to the experiment's flight phases. The flight experiment consisted of a flight from EDVE to EDDP with a low approach and direct return to EDVE. Thus, all flight phases were conducted twice.

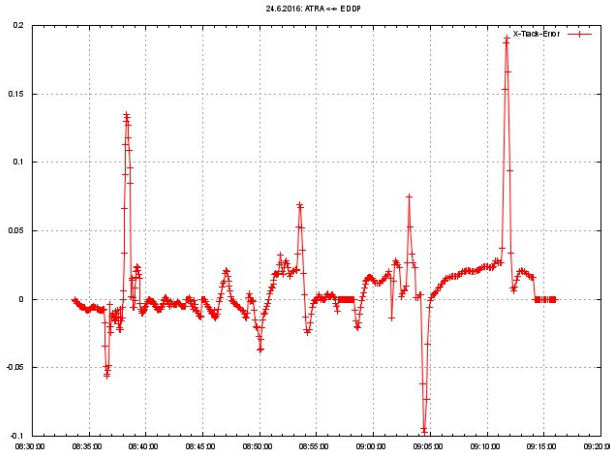


Figure 8. Cross Track Error [NM]

In Figure 8 the cross track error (xCTE) for the outbound flight is displayed. It can be seen that the values stay at a very low level and that the maximal deviations stay within ± 0.18 NM. The highest deviations can be found during approach phase. During cruise the aircraft even stayed within ± 0.07 NM. This is as well reflected in the data evaluation. While the departure phase indicates a very low level of deviations with $\mu(xCTE) = 0.001$ and $\sigma(xCTE) = 0.04$, the cruise phase indicates small, but slightly higher deviations with $\mu(xCTE) = -0.002$ and $\sigma(xCTE) = 0.01$. The approach phase shows the comparably highest deviations with $\mu(xCTE) = -0.01$ and $\sigma(xCTE) = 0.001$. All these data stay well within the required levels of performance defined by ICAO requiring ± 2 NM, ± 1 NM and ± 0.3 NM respectively. The complete data analysis for the cross track error separately provided for each flight phase is given in the table below (Table 1).

The increased lateral deviations during approach result from unforeseen route adaptations that were commanded by ATC to the aircraft, but were not reflected in the aircraft's mission planning. Whereas the aircraft's mission planning is completely based upon published procedures, the ATC in EDDP applied local procedures using vector directions. This required multiple adaptations to the calculated flight path during approach. With the approach segment

outside of the data link range, these adaptations needed to be implemented manually by the experimental pilot on board the aircraft. These deviations are reflected in the recorded data.

Table 1. Cross Track Error [NM] for All Flight Phases

	Flight phase	PBN req. [NM]	$\mu(xCTE)$	$\sigma(xCTE)$
Outbound	Departure	± 1.0	0.001	0.04
	Cruise	± 2.0	-0.002	0.01
	Approach	± 0.3	-0.01	0.001
Return	Departure	± 1.0	0.005	0.02
	Cruise	± 2.0	0.01	0.01
	Approach	± 0.3	0.02	0.04

Secondly, the flight experiment is analyzed with regard to vertical performance accuracy. For the vertical performance different requirements according to the flight phase can be applied. Below 5000 ft MSL the vertical error (x_{AE}) should be smaller than 100 ft. Therefore, this value is set for the data evaluation as limiting value for the approach phase. Furthermore, the recorded data during the cruise phase are compared to the limiting values provided for flight levels (FL) between FL100 and FL150. Therefore, the limiting value is set here to 220 ft. For a detailed evaluation, two representative flight segments from the outbound flight path were extracted to show vertical deviations during cruise (flight segment in FL130) and approach (RNP approach in EDDP). The results from the data analysis for both flight segments are listed in Table 2.

Table 2. Altitude Error [ft] for Cruise and Approach Flight Segments

	Cruise segment	Approach segment
$\mu(xAE)$	1.04	-39.8
$\sigma(xAE)$	19.5	54.13
$\max(xAE)$	36.4	108.0
$\min(xAE)$	-31.4	-128.0
EASA req. [ft]	± 220.0	± 100.0

It can be seen that during the level segment, chosen for evaluating the cruise flight accuracy, altitude deviations between 36.4 ft and -31.4 ft were

recorded. The mean altitude error in this flight segment is $\mu(x_{AE}) = 1.04$ ft with a comparatively high variance of $\sigma(x_{AE}) = 19.5$ ft. These values stay well within the limits defined for the cruise phase. The progress of the altitude error for this level segment is visualized in Figure 9. Overall, the figure and the data show a very high vertical accuracy. However, especially when the flight altitude had to be changed, increased deviations with up to ± 35 ft were recorded. These deviations can be explained by the manual control of the aircraft, resulting in the experimental pilot focusing on lateral deviations and handling altitude commands based on experience and navigation requirements. This circumstance may have caused a delayed implementation of altitude commands.

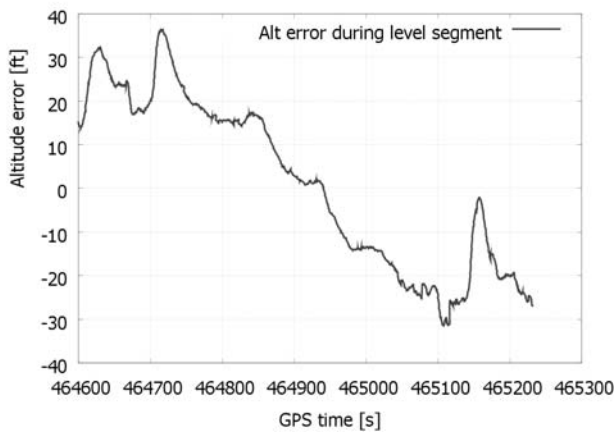


Figure 9. Altitude Error during Level [ft]

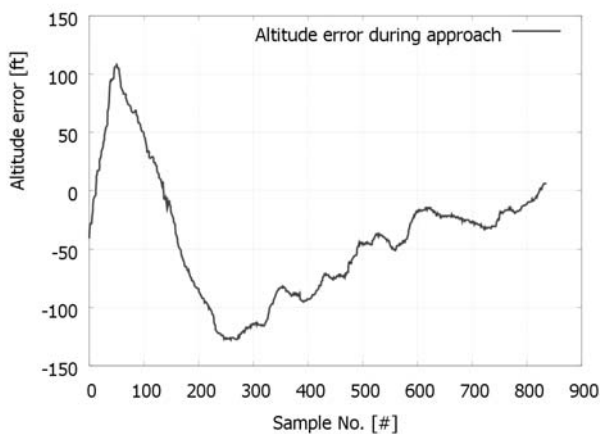


Figure 10. Altitude Error during Approach [ft]

Analyzing the approach phase shows higher deviations than encountered during the cruise phase. For the approach phase a mean value of

$\mu(x_{AE}) = 92.1633$ ft and a variance of $\sigma(x_{AE}) = 26.1201$ ft were recorded. These values represent the accurate path following until the data link connection was disrupted and new commands were given by ATC. The sudden increase of the altitude error, which can be seen in Figure 10, accounts for the direct approach to runway 26, which was not foreseen in the flight plan. With the beginning of the approach to runway 26, the altitude error first increased to values up to $\max(x_{AE}) = 108$ ft and decreased afterwards to values down to $\min(x_{AE}) = -128$ ft. The pilot of the RPAS demonstrator initiated the descent for the approach independently from the planned altitude, because of deviating routing commands from ATC. As a result, the recorded values exceed the limits provided by EASA, and thus require further system and procedure improvements.

Overall, the analyzed data show that especially the lateral deviations stay well within the defined performance requirements. In comparison the vertical accuracy is acceptable, but needs to be improved for real RPAS applications. The vertical deviations in this experiment mainly result from manually following flight director commands (e.g. focusing on lateral accuracy) and unforeseen routing requirements from local procedures.

Issues Encountered

The RPAS flight in controlled airspace can be regarded as safe with regard to robustness and reliability. During departure, the systems had to be realigned, which resulted in a procedure turn (see Figure 2). The only safety critical aspect that was encountered during the experiment occurred during the approach to EDDP in an area where the data link connection was already disruptive. Dynamic adaptations to the flight path initiated by ATC could not be implemented automatically, because local procedures were not considered in the aircraft's flight path calculation. The RPAS demonstrator's path calculation is based completely on published procedures, whereas these are not (or only rarely) applied in day-to-day traffic. In times of day where only low traffic numbers occur, some airports (e.g. EDDP) apply local procedures to guide approaching and departing aircraft (e.g. by giving vector directions), as encountered in the reported flight trial. In case of EDDP another aspect increased the amount of coordination required during the approach

conducted in this RPAS experiment. The published approach procedure from [2] has a final approach fix (“LISBA”, see Figure 4) which is located on the extended runway center line of the adjacent runway. This fact led to confusion and an increase of voice communication required as the air traffic controller wanted to make sure that runway 26R was approached by the RPAS demonstrator. This led to a situation of high workload both on the RPAS demonstrator and on the ground.

Discussion

The results of the flight test and the issues encountered show the necessity of knowledge of local procedures, but also the ability to adapt the flight path during all flight phases. This can be realized for beyond radio line of sight (BRLOS) operations either (a) by using satellite communication or (b) by introducing a new workplace on each hub airport with RPAS traffic. This new workplace would be responsible for controlling approaching and departing RPAS in close coordination with the tower/ATC facility.

The observed flight path following accuracy was adequate to comply with existing regulations. It can therefore be assumed that the setup used in the trial can be used to further demonstration and validation activities.

Integration Concept

Through the lessons learnt by the flight trial, the RPAS integration – at least for large drones operating at hub airports – should include the introduction of a dedicated workplace. This person would act as a dedicated RPAS controller who is able to control all approaching RPAS. The workplace should be co-located with workplaces of the other air traffic controllers who are responsible for manned aviation at the given airport. This would be an extension of the concept proposed in [7]. This setup would have several benefits. Firstly, the location would have a certain degree of security as the workplaces for air traffic controllers are already access controlled – at least at hub airports or ATC centers. Secondly, the RPAS controller would have knowledge about local procedures and specialties at the given airport. This would include standard arrivals and procedures, traffic mix, traffic peaks and more. Thirdly, a direct communication would be ensured with all air traffic controllers involved. The risk of a critical data link

loss would be mitigated. In addition, direct control would be ensured throughout this critical phase of flight with probably the highest traffic density.

On the other hand, this would introduce some drawbacks as well. Control of the approaching RPAS would have to be transferred. This transfer would have to be safe and secure and would add additional burden to the RPAS and ground systems. In addition, some kind of common interface would be required to ensure that the dedicated RPAS controller would be able to control all kinds of approaching RPAS. Manufacturers and operators may be hesitant to hand over direct control of the RPAS. This could be enforced by international regulations and laws at least for given types of airports and operations.

It would also be imaginable that a sectorless concept is used [8]. In such a concept, the dedicated RPAS controller at the destination airport is responsible for the complete flight without the transfer of control. Operators could use an employee of the company to avoid passing control to another entity. It would still have the advantage, that the RPAS controller would have particular knowledge about the destination airport and has complete awareness of the status of the flight (previous faults or malfunctions, performance, etc.).

Conclusion

In this paper the results from a flight experiment were presented that should demonstrate the validity of a concept for RPAS flight in controlled airspace. Initial concept underlying the experiment was the RPAS behaving similar to manned aviation. This “manned aviation look-alike” concept was realized by modifying the on-board and ground systems of the RPAS to enable communication and navigation following the rules for instrumental flight in controlled airspace. Safety was ensured by conducting the flight with a pilot on board the aircraft, who followed the commands from the flight director manually. The flight was planned to follow published procedures (RNP departure/approach and air traffic service routes) with automatic or ground controlled adaptations available for possible ATC reroutings. The flight was conducted between two airports (EDVE and EDDP) in Germany and involved a cruise flight in FL130. The RPAS was controlled by a terrestrial data link system, and it has been taken into account in the flight planning that the data link would be disrupted when entering the

terminal maneuvering area of EDDP. In this paper, not only the flight path following accuracy and the data link performance were analyzed, but most importantly the applicability of existing procedures in controlled airspace when considering BRLOS operations was evaluated.

The results of the flight experiment show a high reliability and robustness of the data link. Further on, no issues with regard to the on-board systems were encountered. Within the data link's range of operation, all required commands and adaptations could be transmitted to the RPAS demonstrator. Furthermore, the flight following performance was evaluated. The RPAS demonstrator followed the provided lateral path with high accuracy at all times, whereas the vertical deviations differed significantly with regard to different flight phases. During level flights a high vertical accuracy was recorded, but during approach the limits defined by EASA were slightly exceeded. These deviations account for one major issue that was encountered during the flight experiment. Despite very detailed preparation of an RPAS flight in controlled airspace by using published routing, including high automation or even autonomy, the integration into airport procedures still requires a close coordination with ATC. Local procedures that often require time-critical adaptation of the RPAS flight path might be in place. Therefore, in this paper a new workplace in the vicinity of the airport (preferably together with tower ATC) is suggested. The role of this new RPAS controller would be to handle all RPAS traffic in close coordination with the airport's ATC. Benefits and drawbacks of this solution still have to be examined thoroughly. Further research will be conducted within the next years to investigate the proposed solution in a first step through human-in-the-loop simulations – together with air traffic controllers and new RPAS controllers – and in a second step through flight experiments.

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